With the compliments of Alvin J. Cox

SAND-LIME BRICK AND ARTIFICIAL SAND STONES IN THE PHILIPPINES

By Alvin J. Cox, W. C. Reibling, and F. D. Reyes
(From the Laboratory of General, Inorganic and Physical Chemistry, Bureau of Science, Manila, P. I.)

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SAND-LIME BRICK AND ARTIFICIAL SAND STONES IN THE PHILIPPINES.

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(*From the Laboratory of General, Inorganic, and Physical Chemistry, Bureau of Science, Manila, P. I.*)

INTRODUCTION.

Sand and limestone, although the most common and familiar and perhaps the least appreciated of mineral resources, constitute an asset of immense importance to any country. Limestone of excellent quality is abundant throughout the Philippine Islands [1] and guarantees to this Archipelago important industries, among which the manufacture of artificial stone and brick from sand and lime is certain to become exceedingly important.

In the Philippines, the varieties of stone which are known to be good for building and construction purposes are not very numerous, and it is unfortunate that with the exception of a few deposits of volcanic tuff ("adobe" stone), those which exist are not conveniently located for use. In the past, most of the permanent buildings were constructed of volcanic tuff, and its low and uncertain strength [2] made very massive construction work necessary. Moreover, as the stones have a dirty color and are only roughly shaped by hand into rectangular blocks 18 by 18 by 50 centimeters in size, they give structures a very unclean, irregular, and aged appearance.

A superior volcanic tuff is quarried at Meycauayan, Bulacan, about 10 kilometers from Manila. Six-inch cubes of this material gave a crushing strength of 1,047 pounds per square inch (73.6 kilograms per square centimeter). However, the data recorded in Table I show that most of the volcanic tuff extensively

[1] Adams, G. I., *This Journal, Sec. A* (1910), 5, 57–117. Smith, W. D., *ibid.* (1906), 1, 1043–1061; *Sec. A* (1910), 5, 307–363.

[2] Cox, Alvin J., *This Journal, Sec. A* (1908), 3, 191.

used throughout the Island of Luzon is a very poor building material.

TABLE I.—*Compression strength of 6-inch cubes of volcanic tuff.*

Quarry.	Date mined.	Weight per cubic meter (average).	Total strength in pounds.		Average strength in pounds per square inch.	
			First crack.	Ultimate.	First crack.	Ultimate.
		Kilos.				
Binangonan	Apr. 17, 1876	1,540	[a] 4,300	[a] 6,500	263	385
			6,500	12,500		
			5,650	12,800		
			16,200	16,300		
Cauit	July 14, 1879	1,480	5,300	6,550	173	193
			9,700	9,900		
			3,400	4,800		
			6,500	6,600		
Unknown	Sept. 8, 1880	1,456	8,550	8,850	184	212
			4,100	6,675		
			8,000	8,550		
			5,900	6,350		
Bañadero	July 1, 1882	1,520	4,300	7,100	159	230
			3,500	7,000		
			5,600	8,000		
			9,400	11,040		
Do	Jan. 17, 1912	1,560	2,300	4,250	123	147
			5,250	5,400		
			3,400	3,700		
			6,700	7,800		
Binangonan	----do----	1,665	10,000	16,425	276	467
			8,500	16,950		
			7,200	16,650		
			14,000	17,100		
Cauit	----do----	1,665	8,000	6,525	185	211
			5,100	8,760		
			6,900	7,825		
				7,250		

[a] Corners of cube broken off.

Recently, important structures have been built almost exclusively of reinforced concrete, and concrete blocks have been used for small buildings. The high cost of cement and good

aggregate makes such work expensive, but in spite of this and the great need of a cheap and durable building stone the sand-lime brick industry has not been introduced into these Islands in any form.

The latest and best methods for the manufacture of artificial sandstone place the process midway between a quicklime and a cement industry, and important technical considerations are involved. The most efficient methods of quarrying and burning limestone, of slaking lime, of mining and grinding the raw materials, and of molding and hardening the products have not yet been determined. Also, the effect of impurities such as clay, feldspar, and dehydrated kaolin have not been thoroughly investigated. However, sufficient information is available to insure the commercial value and feasibility of this industry in the Philippines if it is carefully and conservatively managed after a proper selection of a factory site, raw materials, process of manufacture, and machinery. On the other hand, if the cost of production includes large items for "promotion," "secret formulas," etc., the stability and success of the enterprise are questionable.

This laboratory is carrying on a thorough investigation to ascertain the suitability and relative efficiency of available raw materials for the manufacture of sand-lime bricks and to study some of the most important technical considerations involved. This work is far from complete, but owing to numerous requests for data on the subject the publication of these preliminary notes seems advisable. The information herein contained is not intended to cover all the possibilities and processes of the industry nor the technical conditions involved. A discussion of these points may be found elsewhere.[3]

CARBONATE BINDER.

Previous to 1880 lime-mortar bricks were manufactured simply by molding a stiff mixture of sand and slaked lime by hand and then exposing it to the sun and air. The hardening process involved depends primarily upon the conversion of calcium hydroxide into calcium carbonate. It is slow and comparatively expensive, as several months' time and a very large percentage

[3] Peppel, S. V., *Bull. Geol. Surv. Ohio* (1906), 5. Essais sur le Silico Calcaire, by E. Leduc, current numbers of *Cem. & Eng. News*, and the *Tonind.-Ztg.*

of lime are required for suitable results.[4] On the other hand, the durability of lime mortar is unquestionable. Lime-mortar brick buildings in Germany, England, and America which can be readily traced considerably over fifty years are still in excellent condition. More rapid and efficient methods of accomplishing the same results have practically abolished this process of manufacture, but in some parts of the Philippine Islands the conditions are such that the old process might be employed with success. In Masbate, Surigao, Cebu, Benguet, and other provinces there are places where an abundance of firewood, limestone or seashells, and sand are available; and in such places the ordinary laborer could build his own lime-kiln and wooden molds and manufacture mortar brick without capital.

When it was discovered that mortar brick hardened equally well in an atmosphere of carbon dioxide or waste furnace gases, the factor of time was largely eliminated. The process was further improved by molding the bricks under great pressure and also by hardening with carbon dioxide (CO_2) under pressure. We do not believe that any of these methods will ever become of commercial importance, because the conversion of lime into calcium carbonate is confined more or less to exposed surfaces of the mortar as well as to the individual particles, and this precludes the possibility of great strength and uniform and reliable results.

CALCIUM HYDROSILICATE BINDER.

In 1880 the researches of Michaelis Sr. of Berlin resulted in the process of making sand-lime brick in which the sand particles are bound together by calcium hydrosilicate. The principle involved is very simple. Sand or finely crushed stone is thoroughly mixed with about 10 per cent of slaked lime and the moist mixture molded under great pressure into any desired shape. When molded, the bricks are piled on trucks and wheeled into a large steel chamber where they are subjected to the action of live steam under pressure. The time required for proper steaming depends upon the steam pressure employed, but eight hours at 130 pounds per square inch (9.13 kilograms per square centi-

[4] The crushing strength of lime mortar is only about 150 to 300 pounds per square inch (10.5 to 21.1 kilograms per square centimeter) and this maximum strength is attained in about one and one-half years.

meter) gives very satisfactory results. After the steam treatment, the bricks are ready for immediate use.

The best commercial practise results in a very desirable product. The strength is as high as, and more uniform than, a good quality of stone, and it increases with age; the absorption of moisture is less than that of any other except vitrified brick, and it is remarkably little affected by heat. The best commercial practise in America produces a sand-lime brick with compressive and tensile strengths ranging from 4,000 to 6,500 and from 300 to 370 pounds per square inch (280 to 460 and from 21 to 26 kilograms per square centimeter) respectively. These figures can be increased to 8,500 for compression and 550 for tension, but a compressive strength of 4,000 and a tensile strength of 300 pounds per square inch are sufficient for all ordinary brick construction work.

The sand-lime brick industry has reached its highest state of commercial success in Germany where over 300 factories have been in successful operation for many years. Practically no face bricks are manufactured, but the largest factory, the Berliner-Kalksandsteinwerke near Berlin, operates continuously and produces 440,000 bricks daily. The success of the industry in Germany is due largely to the control of an association of sand-lime brick manufacturers which, since 1903, put its members under obligation to manufacture brick having a crushing strength of not less than 2,000 pounds per square inch (140 kilograms per square centimeter). The sand-lime brick industry has not gained much prominence in the British Isles, for the reasons that in England there are immense deposits of first-class clay which enable clay bricks to be produced and sold at a very low price, while in Scotland good stone quarries are plentiful and building stone is a cheap commodity. The industry was introduced into the United States in 1901, but did not make much progress until 1903 when 16 plants reported products valued at 155,040 dollars. During the next four years the industry grew rapidly, 94 plants reporting 1,225,679 dollars' worth of products in 1907. Since then it has declined, and in 1911 there were but 66 firms, and the total value of their production dropped to 879,664 dollars.[5] A careful investigation of the cause of this decline has led us to believe that it was due to the marketing of an improperly prepared product and to the fraudulent practises of

[5] *U. S. Geol. Surv. Press Bull.* (1912), 53, 1.

promoters and manufacturers. Such practises serve to destroy the confidence of the financier, architect, and general public, and their object lesson is one which must be heeded. A competition for cheapness and not for quality is the most frequent and certain cause of failure.

Michaelis permitted the letters patent on this process of hardening by superheated steam to lapse without commercial application, and therefore it is public property. No secret formulas or chemicals are necessary, and, if the available raw materials are satisfactory, manufacturers are willing to enter into contract to furnish working drawings and blue prints for the necessary foundations and buildings, equip and install the machinery, and put the whole plant in proper operation. There are a few patents concerning the economy of manufacture which have more or less merit, but recently an all-American system with no patents has been introduced.

MIXED CARBONATE AND SILICATE BINDER.

A combination of the two hardening processes just described provides for the introduction of carbon dioxide from the lime kilns and steam into closed iron chambers. The binding material formed at atmospheric pressure is mainly calcium carbonate. The amount of calcium silicate formed increases with the steam pressure, while that of the carbonate decreases.

Peppel [6] believes that sand bricks with a silicate bond are the only ones which will ever take any important place in the world's markets, but an inspection of the works and products of the British Stone and Marble Co., Ltd., Ponders End, Middlesex, England, gives an entirely different impression. This company uses and claims to own a process whereby the débris of any suitable building stone is first reduced by mechanical disintegration to a granular state and then built up again into stone practically indistinguishable from the quarried product. As its trade name indicates, it is "reconstructed stone." The characteristic features of the natural product are produced with accuracy while the defects are eliminated. The process consists in disintegrating quarry débris without destroying the form of the original component grains, mixing the resultant grit with a definite proportion of lime calcined in closed retorts, slaking the mixture thoroughly, and, after the addition of considerable water, consolidating under great pressure into blocks of any desirable size

[6] *Loc. cit.*

and shape. These blocks are of the consistency of soft chalk when they leave the press, and since they are homogeneous they can be easily and rapidly shaped with saws and cutting tools. After being cut or carved to any required design, the material is dried at a temperature of 40° to 50° and placed in steel tanks from which the air is exhausted; carbon dioxide previously expelled from dolomite is then admitted by successive stages together with some steam until the carbonation of the hydrate of lime is complete. The stone is then ready for sale, unless sanding or gritting is desired.

Any kind of sedimentary rock, whether granular or metamorphic, can be reconstructed by this process which converts both hard and soft, perfect and imperfect, natural products into uniformly hard and durable stone of superior quality and appearance. Quarry débris is preferable to ordinary rock only because of the difference in the state of pulverization. It would be too expensive to crush hard rock solely for this purpose, but there are many soft stones in the Philippines which crush so easily that the cost would not be prohibitive.

Information regarding the durability of reconstructed stone is not available, but the bonding is unquestionably uniform and complete throughout the mass, which indicates that it should weather with uniformity and prove durable even under very severe atmospheric conditions. The resistance to crushing stress of 3-inch cubes of reconstructed stones is given in Table II.

TABLE II.—*Crushing strength of reconstructed Bath stone.*[a]

Test No.	Total strength in pounds.		Average strength in pounds per square inch.		Average strength in tons per square foot.	
	Slightly cracked.	Crushed.	Slightly cracked.	Crushed.	Slightly cracked.	Crushed.
2424	109,600	127,700	11,264	13,124	724.4	844.0
2422	96,700	120,100	9,938	12,343	639.1	793.8
2623	84,000	98,200	8,571	10,020	551.2	644.4
---------	96,765	115,333	9,924	11,829	638.2	760.7

[a] Tests made by David Kirkaldy and Sons, London, England, and published in the manufacturers' pamphlet, "About Reconstructed Building Stones and Marble."

The poor fire-resisting properties of this stone are detrimental to its efficiency as a constructive material. The binder is principally calcium carbonate, and a red heat will cause disintegration.

USES FOR SAND BRICK AND ARTIFICIAL STONE.

Good sand-lime bricks are sanitary, their hygroscopic properties are very slight (about 1.5 per cent in air), they absorb very little water when wet (6 to 10 per cent), do not effloresce, and in every way apparently meet the demands of tropical climatic conditions as a desirable structural material.

We have considered only the application of these processes to the manufacture of ordinary building stone. Fortunately there are other uses to which either the reconstructed stone or the sand-lime process can be applied; namely, the manufacture of building blocks, sills, caps, fence posts, slabs, tiles, wall-copings, templates, jambs, lintels, steps, landings, curbstones, pipes, sidewalk slabs, and ornamental work such as elaborate moldings, monuments, flower pots, posts, vases, statuary, garden seats, and artificial marble. Plate I shows a small segment of a reinforced, reconstructed-stone beam designed to support glass plates on the roofs of hothouses. The photograph shows the smooth hard surfaces and clean edges obtainable, and suggests a wide range of application for artificial sandstone products such as are shown in Plate II. The various articles may be manufactured in trade sizes and patterns by tamping portions of the raw mixture into special molds and then hardening in the usual manner; or the material can be pressed into blocks, and, while still soft, cut by hand or machine into almost any design. Frequently the profits of a sand-brick plant can be augmented by manufacturing such articles, and the expense for the necessary additional equipment is comparatively small.

The manufacturer of sand brick or artificial stone must depend upon large and fairly regular sales for profitable returns. A factory with a capacity and market below 15,000 bricks per day would probably not be a very good investment. It will require several years to create a demand in the Philippines large enough to keep a factory of greater capacity in constant operation. On the other hand, there is a demand for such articles as fence posts, tiles, steps, sidewalk slabs, pipes, and ornamental work, and a plant equipped to manufacture these as well as the ordinary building stone has an opportunity successfully to establish a good and growing business.

The usual, continuous horizontal joints of brick walls are a source of weakness. This is especially undesirable in countries subjected to earthquake shocks, and should be overcome by special

forms of brick which, when properly laid, result in broken and bonded horizontal as well as vertical joints,[7] or by interlocking or reinforcible building blocks, similar to concrete blocks now in use, both of which can be easily manufactured.

RAW MATERIALS.

Sand brick or reconstructed stone can be manufactured on a commercial basis with either calcium carbonate or calcium hydrosilicate as the binding material. The former has for its advantage a minimum fuel consumption, while the latter withstands best the effects of fire and, in all probability, atmospheric and chemical influences. The calcium carbonate process is not dependent upon the chemical composition of a sand or stone, but silica in a suitable chemical or physical condition is essential to the steaming process. With the exception of these differences, further consideration can be limited to the calcium hydrosilicate, the so-called sand-lime brick process.

Siliceous material.—Generally speaking, common siliceous sand is the most desirable and the cheapest source of silica for the sand-lime brick industry. A fairly good sand-lime brick can be obtained with almost any sand, but economy in manufacture limits the physical and chemical properties rather sharply. A comparatively pure and fine sand is essential to a cheap and durable product, and silica which is capable of combining with the lime must be present in quantity. Sand grains too large to pass a sieve having 8 meshes to the centimeter (20 meshes to the inch) are undesirable, and particles sufficiently fine and numerous to enable sufficient silica to combine with the calcium oxide are necessary.[8] In order to produce a dense brick, there should be a good gradation of sizes and a low percentage of voids. Very few natural sands have this desirable granularimetric composition, and the influence of fineness upon the quality of the brick is so great that usually it is advisable to resort to screening and grinding or what is known as the division method. Screens are employed to remove the large particles, and granularimetric gradation is accomplished by grinding part of the sand and then remixing this pulverized product with the whole. The lime is ground with the sand in order to secure as thorough a mixture as possible.

[7] Strale, A. N. H., Pat. No. 1,021,851, April 2, 1912.

[8] Gasenapp, M., *Tonind.-Ztg.* (1901), 762.

Quarry débris, soft stone, and volcanic tuff are often suitable sources of silica and in many instances are capable of being crushed into desirable sand at no greater cost than that required for the installation of the division method. Siliceous sands, soft sandstone, and volcanic tuff are plentifully distributed throughout the Philippine Islands.

Richly colored siliceous materials naturally give bricks of a similar color, but otherwise a pleasing white to gray is obtained which is more or less spotted according to the color, quantity, and shape of the coarse grains. The color is permanent, unless oxidizable mineral pigments such as iron are present.

Lime.—In ordinary lime mortar, magnesia is not considered detrimental, but it can not be substituted for calcium oxide in the sand-lime brick industry on account of its slow slaking properties. Other impurities in the limestone, such as sand, clay, and iron oxide, should also be avoided. They tend to produce slow slaking, fluxed and overburned lime,[9] as well as to decrease the efficiency by dilution. On the other hand, a comparatively pure calcite limestone gives the best results, and can be burned and slaked with the least expense and difficulty. It is absolutely necessary that the free lime be thoroughly hydrated before the bricks are molded; otherwise, the expansion due to subsequent hydration is very apt to cause the bricks to swell or crack and split.

In the Philippines, the most generally distributed calcareous material is a hard limestone of Miocene age which is usually associated with shales and sandstones. It occurs abundantly on nearly every island of the Archipelago and is uniformly remarkably pure.[10] Its fitness for the sand-lime brick industry is demonstrated by the analyses given in Table III.

[9] The evil effect of free lime and magnesia in sand-lime brick is in all respects similar to their effect in indurated Portland cement, and the slaking properties of free lime under all conditions of burning, grinding, and seasoning are important considerations. *Cf.* Reibling W. C. and Reyes, F. D., *This Journal, Sec. A* (1910), 5, 117–142; (1911), 6, 207–252; (1912), 7, 135–191.

[10] Cox, A. J., *This Journal, Sec. A* (1909), 4, 211; Pratt, W. E., *Min. Resources P. I. for 1910, Bur. Sci., Div. Min.* (1911), 61.

TABLE III.—*Analysis of Philippine limestones.*

Sample No.	Source.	Classification.[a]	Constituents.						
			Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Alkalies ($Na_2O + K_2O$).	Loss on ignition (mostly carbon dioxide).
1	Mount Licos near Camansi coal mine.	Miocene limestone.	0.36	0.18		55.62	0.00		43.93
2	Marble, Romblon, Capiz.	do	0.10	0.17		55.23	0.45		43.80
3	Batan Island, Albay.	do	0.97	0.56	0.36	53.86	0.19		43.18
4	Cebu, Cebu	Coralline limestone (Pliocene).	1.31	3.90		52.01	0.63		
5	Danao, Cebu	do	2.61	2.23		52.85	0.88		
6	Guimaras Island.	do	6.28	4.33		45.76	2.70		
7[b]	Naga, Cebu	Coralline marl (Pliocene).	11.12	4.28		45.65			
8	do	do	14.10	5.77		43.27			
9	do	do	11.57	4.62		46.25			
10	do	do	12.68	5.75		43.36			
11	do	do	9.43	4.02		47.53			
12	do	do	10.28	0.63	3.28	45.96			
13	do	do	8.37	0.22	3.25	49.84	1.02		
14	do	do	11.99	0.57	2.90	45.69			
15	Argao, Cebu	Bedded marl or chalk (Pliocene).	8.93	6.45		44.35	2.70		
16	Near Camansi	Argillaceous limestone (Miocene).	29.00	11.38	5.35	26.25	0.65	1.98	23.00
17	do	do	24.02	7.49	2.00	33.88	2.12		28.25

[a] Made by W. E. Pratt.

[b] Analysis typical of a series of best hole samples representing a thickness of from about 15 to 30 meters over an area of about 15 hectares.

In general, the physical condition of Philippine limestones is also very satisfactory. Their hardness, while sufficient to insure solidity during the burning process, is not great enough to

prevent easy quarrying. The burning and slaking of lime and its incorporation into sand are apparently simple operations; however, in reality, they involve complicated financial and technical considerations which are almost entirely ignored in local practises. The Filipinos manufacture on a small scale a very poor lime from seashells. They burn with wood or sawdust, and the analysis given in Table IV is typical of the poor quality produced.

TABLE IV.—*Analysis of burned shell taken from a Gagalañgin lime kiln near Manila.*

Constituent.	Per cent.
Total calcium oxide (CaO)	61.4
Carbon dioxide (CO_2)	14.5
Clay, sand, etc.	24.1
Total	100.0
Calcium carbonate [a] ($CaCO_3$)	32.9
Calcium oxide in calcium carbonate (CaO as $CaCO_3$)	18.4
Total impurities ($CaCO_3$ + sand, clay, etc.)	57.0
Available lime [a] (CaO)	43.0

[a] Calculated.

Lime in small quantities is also manufactured from lime rock, but it usually contains at least 40 per cent of underburned material. The only first-class lime which can be purchased in the local markets is that which has been imported from Hongkong or other foreign ports.[11] The prospective manufacturer should burn his own lime, and supply as well the demand for this material throughout the Islands.

The location of the raw materials with respect to the market and the transportation rates are considerations of great importance. The sand or crushed stone constitutes about nine-tenths of the finished product, and, taking into account only the cost of transportation, the relative importance of the location of the limestone, sand, and market, with respect to the plant may be represented by the figures 1, 9, and 10 respectively. The cost of transportation will be reduced to the lowest figure if the location of the distributing market and silica and limestone deposits coincide. Otherwise, the location of the sand with respect to the market is much more important than that of the limestone. The plant should be located as near the distributing center as is practicable.

[11] Recent imports of slaked lime from Hongkong showed a purity of about 85 per cent.

PROCESS OF MANUFACTURE.

While there are several processes and machines, there are but two distinct systems for controlling the raw mix; namely, the "silo system" and the "pre-hydrating system."

Silo system.—The lime is pulverized, mixed with sand, moistened, and placed in a bin where it is allowed to remain a sufficient time for the lime thoroughly to hydrate or slake. According to E. Leduc and Ch. de la Roche,[12] "stale or partly carbonated limes account for a great number of failures in the manufacture of sand-lime brick," where the silo system is used. Their results (Table V) show considerably less strength when the lime had been exposed to air for four days, and they also obtained less strength when the quicklime had been less finely subdivided or less thoroughly mixed.

TABLE V.—*Effects of air slaking and screening the lime and negligent mixing (bricks steamed for six hours at 120 pounds pressure).*

Lime in the mixture.	Sand in the mixture.	Initial compression of the mixture.	Average resistance to pressure in pounds per square inch.			
			Mix No. 1.	Mix No. 2.	Mix No. 3.	Mix No. 4.
			Results obtained with pure, nonaërated, screened lime, and good mixing.	Same as No. 1 except that the mixing was less thorough.	Same as No. 1 except that the lime was partly carbonated by a 4-day exposure to the air.	Same as No. 1 except that the lime was not sieved.
Per cent.	*Per cent.*	*Pounds.*				
8	92	3,750	1,680	1,340	1,088	1,340
10	90	3,750	2,025	1,470	1,515	1,530
12	88	3,750	2,005	1,480	1,575	1,845
8	92	7,500	2,145	1,750	1,546	1,742
10	90	7,500	2,456	1,865	1,772	1,818
12	88	7,500	2,615	2,130	1,988	2,080

The pre-hydrating system.—This process consists in the hydration of the lime in the hardening cylinders before it is mixed with the sand. This method of slaking utilizes the heat of hydration and insures the use of lime which will not undergo further slaking during the steaming process; but according to P. L. Simson,[13] pre-hydrating systems are gradually being elimi-

[12] *Cem. & Eng. News* (1911), 23, 231.
[13] *Ibid.* (1912), 24, 164.

nated from up-to-date practise in Germany, where hydrating the lime with all the sand in silos or slaking drums is advocated by the experts.

The advisability of slaking some limes with steam under pressure before mixing with the sand is illustrated by fig. 1, Plate III, and fig. 2, Plate V. In both instances the same raw meal was employed, but the former was made according to the silo system and the latter by pre-hydration. In this instance the pre-hydration was accomplished simply by treating the quicklime with a slight excess of water in a closed air-tight retort. The heat of hydration was sufficient to generate and maintain steam under pressure for several hours.

The degree of compactness affects some mixtures more than others, but in all instances a molding pressure of from 10,000 to 15,000 pounds per square inch (700 to 1,050 kilograms per square centimeter) is required for maximum strength. However, the efficiency of either the raw materials or the commercial value of the finished product does not depend solely on the strength of the brick obtained, but also upon appearance, density, absorption, fire-resistant properties, etc. Furthermore, these are all subject more or less to the conditions of manufacture, such as granularimetric composition, thoroughness of mixing, and molding pressure. A certain coarseness of grain and porosity often improves the fire-resistant properties of a brick, but this is gained only at a sacrifice of strength and density. A practically unlimited range of colors can be produced by the use of artificial coloring matter. The ordinary cheap mineral pigments give fairly satisfactory result, but Glasenapp [14] advocates the staining of sand-lime brick by a new method in which the colors are formed by the reaction of calcium hydroxide with salts of various metals. If polished surfaces are desired, coarse grains of hard durable stone are essential. Marble effects and staining are usually accomplished at the expense of the strength.

Fuel.—Almost any commercial fuel is capable of meeting the demands of this industry. The highest temperature required is for burning the limestone, and as this should be from about 950° to 1,050°, firewood, coal, crude petroleum, natural gas, coke, reduced oil or petroleum residuum, water and producer gases, and even lignites and peat compressed into briquettes have been successfully employed. A long flame of low intensity tends to produce a uniform distribution of heat and to prevent over-

[14] *Tonind.-Ztg.* (1899), 1421.

burning, while the presence of moisture or steam lowers the temperature at which limestone is decarbonated. Wood is the fuel which is best suited technically for burning limestone. Coal, to give the best results, should be high in volatile constituents, hydrogen, and calorific value, and low in fixed carbon, sulphur, and ash.

LABORATORY METHODS.

In testing the siliceous materials, the following general method of making sand-lime brick was used. When necessary, the sand or crushed stone was dried in the air and ground to almost its final degree of pulverization. Then 10 per cent by weight of dry, pulverized, hydrated Montalban lime was ground with part of the siliceous material, and the whole thoroughly mixed before and after the addition of water. The mixture was then molded into bricks under pressure as indicated in the tables, and finally the bricks were subjected to the action of live steam at a pressure of 125 pounds per square inch (8.79 kilograms per square centimeter) for five and one-half to eight hours, as specified.

The first experiments were made to ascertain only the general adaptability of the available raw materials, and no attempt was made to secure better conditions and results than would have been obtained had the material been subjected to an ordinary commercial process for the manufacture of common brick. In fact, it was our desire to make the test a severe one, and for this reason the bricks were molded at the low pressure of 4,600 pounds per square inch or less, steamed only five and one-half hours, and no attempt was made to secure the greatest density or most desirable fineness. After this, the materials were tested under more favorable conditions in order to ascertain their fitness for the manufacture of face brick, tiles, ornamental stonework, fire brick, etc. We have not had sufficient time to make a detailed study of each material such as would enable us to subject each to ideal conditions of manufacture, and the results obtained and recorded throughout this paper can be, and in many instances have been, improved by more thorough mixing, better granularimetric composition, and a higher molding pressure.

P. L. Simson [15] has pointed out that the ordinary American method of testing the strength of bricks on their largest flat surface gives about 30 per cent higher results than the German method of dividing the brick in two and placing one-half above

[15] *Cem. & Eng. News* (1912), 24, 160.

the other. Our bricks were either tested in cubical form or standing on their smallest flat surface, and consequently the results represent a minimum strength. The strength obtained is considered as very satisfactory, and even the lowest is regarded as sufficient for ordinary local construction work, as a 1:2:4 concrete mixture as ordinarily prepared from Philippine aggregate will crush under a pressure seldom exceeding 2,000 pounds per square inch (140 kilograms per square centimeter). On the other hand, the poorest result was much stronger than the best volcanic tuff. However, it is evident that a high molding pressure is essential if a strength above 2,000 pounds is required.

A thorough investigation of the efficiency of the raw materials with respect to the fire-resistant properties of the sand-lime bricks has not yet been accomplished. Certain samples of the sand-lime bricks described in the following pages were heated for thirty minutes in a muffle furnace at about 1,100° and then quenched in water. Plate VIII shows five instances where the bricks remained perfectly sound after such treatment.

RAW MATERIALS IN THE VICINITY OF MANILA.

The high cost of land transportation throughout the Philippine Islands makes the location of the factory with respect to the market and raw materials a consideration of more than usual importance. Eventually, sand-lime brick factories should be installed at all of the principal commercial centers of the Archipelago where suitable raw materials are available in order to reduce the necessary transportation to a minimum. For several years to come the demand in the Philippines will probably not be great enough to support more than one, or possibly two, sand-lime brick plants; and since Manila appears to be the most desirable location for the first plant, the near-by raw materials have been given primary consideration.

Lime.—The most available and important calcareous raw materials in the vicinity of Manila are two exposures of Miocene limestone, one near Montalban, about 30 kilometers from Manila, on a line of the Manila Railroad Company and the other in a semi-mountainous country about 7 kilometers north of Binangonan, Rizal Province, and about 20 kilometers from Manila. There is communication between Binangonan and Manila by means of launches and scows via the Pasig River and Laguna de Bay. The limestones in both places are hard and crystalline, and the deposits are uniform in chemical composition. The analyses given in Table VI show that they are almost pure calcite.

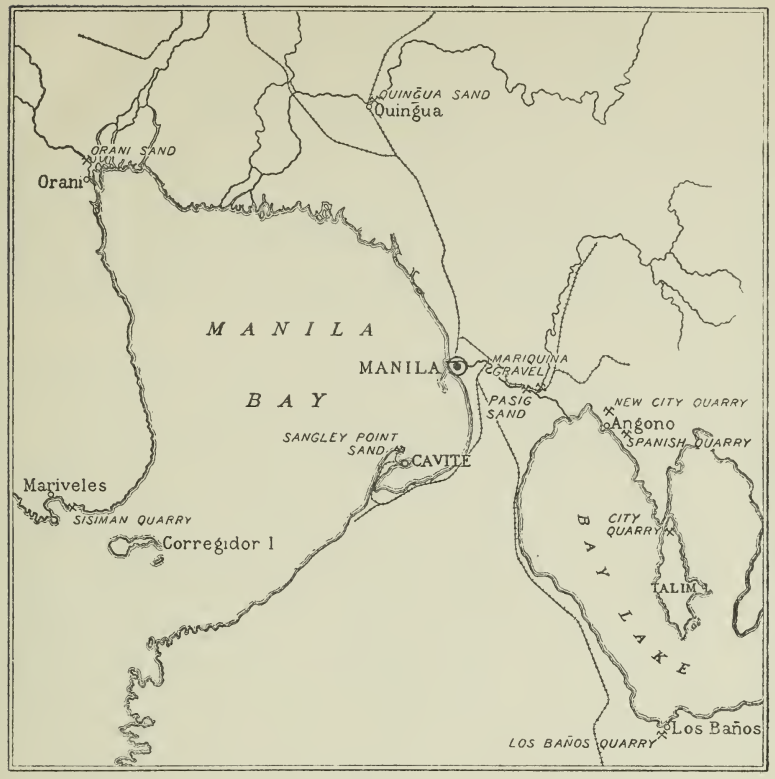

FIG. 1.—The vicinity of Manila (1 millimeter equals 1 kilometer).

TABLE VI.—*Ultimate chemical composition of Binangonan and Montalban limestones.*

Constituent.	Limestone from Binangonan.	Limestone from Montalban.[a]
	Per cent.	*Per cent.*
Water at 110° C	0.16	0.25
Silica (SiO_2)	1.12	0.94
Iron and aluminum oxides (R_2O_3)	0.15	1.14
Calcium oxide (CaO)	53.78	54.61
Magnesia (MgO)	1.19	0.22
Combined alkalies ($K_2O + Na_2O$)	0.77	0.56
Sulphuric anhydride (SO_3)	trace	trace
Loss by ignition	43.15	42.79
Lime calculated to calcium carbonate ($CaCO_3$)	96.03	97.52

[a] Analyzed by Forrest B. Beyer.

Binangonan limestone is the more available to Manila because of the more difficult water transportation or the expense of the necessary railroad transportation from Montalban to Manila. In either place there is an abundant supply of almost pure limestone within 30 kilometers of Manila.

The siliceous materials in the vicinity of Manila vary greatly in chemical and physical properties, but after careful consideration we were able to select 8, so that the variety included the principal characteristics of all of probable importance. Their character and usefulness will be discussed in conjunction with their location.

Beach sand.—South of Manila there is no stream entering the Bay which contains deposits of sand. Between 12 and 14 kilometers from Manila at Sangley Point and at Las Piñas, with which there is water communication, beach sand is abundant. This sand is derived principally from basaltic rocks which occur fragmentally in the tuff formation which borders Manila Bay. The grains are in an advanced stage of decomposition and are easily crushed. The Manila beach itself at Maytubig has similar, but very fine, sand from which fairly good sand-lime bricks have been manufactured. The efficiency of this fine beach sand is of more than ordinary importance because it is the only available siliceous material which is fine enough to require no grinding, and also because it is so abundant and easily procured. This work was completed before property owners near Maytubig protested against the removal of sand. Now a supply will have to be obtained from a greater distance or dredged from the bay.

TABLE VII.—*Maytubig beach sand and its efficiency as a sand-lime brick material.*

Description and classification.	Content of silica (SiO_2).			
	Soluble in hydrochloric acid (HCl).	Soluble in sodium carbonate (Na_2CO_3).	Free silica or quartz.	Total silica.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
A very fine-grained sand containing magnetite, considerable partly kaolinized feldspar, and a little quartz. The grains of magnetite, pyroxene, and hornblende are generally rounded, and those of feldspar and quartz angular	0.37	14.86	2.61	60.51

TABEE VII.—*Maytubig beach sand and its efficiency as a sand-lime brick material*—Continued.

CHARACTERISTIC GRANULARIMETRIC COMPOSITION.

Standard sieve No.	10	20	30	40	50	60	80	100	200
Meshes per linear inch	10	20	30	40	50	60	80	100	200
Diameter of openings in millimeters	1.85	0.92	0.56	0.47	0.34	0.28	0.20	0.15	0.06
Percentage of sand passing through specified sieves	100.0	100.0	99.9	99.7	98.0	96.5	80.4	51.7	6.0

THE SAND-LIME BRICK.

Mixture No.	Fineness of sand as used.	Dimensions of brick.	Area of bearing surface.	Duration of steam treatment.	Molding pressure per square inch.	Compresssive strength.	
						Total.	Per square inch.
		Inches.	*Sq. in.*	*Hours.*	*Pounds.*	*Pounds.*	*Pounds.*
1	As received	2×2×2	4.0	5.5	4,600	7,200	1,800
2	One-fourth pulverized	2×2×2	4.0	5.5	4,600	7,720	1,930
1	As received	2×2×2	4.0	8.0	10,640	13,880	3,470
2	One-fourth pulverized	2×2×2	4.0	8.0	10,640	11,200	2,800
3	One-tenth pulverized	3×3×2.25	6.75	8.0	10,000	20,560	[a] 3,200
3	do	3×3×2.25	6.75	8.0	15,000	25,920	3,840
4	As received	2×2×2	4.0	8.0	7,640	8,000	2,000
4	do	2×2×2	4.0	8.0	10,000	13,360	[b] 3,340

Mixture No.	Molding pressure in pounds per square inch.	Density.		Absorption after 24 hours in water.	
		Air dry.	Dried at 110°.	Air dry.	Dried at 110°.
4	10,000	2.08	2.01	7.40	11.0

[a] Plate III, fig. 2, is a photograph of the finished product.

[b] Plate IV, fig. 2, is a photograph of the finished product after an attempt had been made to polish the front surface. This brick had a density (air-dried) of 2.08 and it absorbed 7.4 per cent by weight of water after being submerged for twenty-four hours.

In all instances, the bricks had a pleasing steel-gray color which after several months' exposure to sun and rain had not changed, but the surface would not take a good polish.

Pasig sand.—Most of the sand used in Manila is dredged or dipped up in baskets from the Pasig and its principal tributary, the Mariquina River. A good sand-lime brick can be made with this sand, but the supply is rapidly decreasing owing to the great quantity used for concrete construction work.

TABLE VIII.—*Pasig sand and its efficiency as a sand-lime brick material.*

Description and classification.	Content of silica.			
	Soluble in hydrochloric acid (HCl).	Soluble in sodium carbonate (Na_2CO_3)	Quartz.	Total silica.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
A clean, rounded, pebble sand derived principally from andesite and basaltic rocks. Quartz is present in amounts up to 12 per cent, and iron minerals are also more or less abundant. The prevailing color is a dark slate	0.18	18.43	11.20	62.72

GRANULARIMETRIC COMPOSITION.

Sieve No.	10	20	30	40	50	60	80	100	200
Per cent of sand passing through specified sieves [a]	99.5	99.0	95.0	71.0	36.0	20.5	10.0	2.0	trace
Per cent of sand passing through specified sieves [b]	96.0	64.0	42.0	38.0	23.5	10.0	5.0	2.6	trace

THE SAND-LIME BRICK.

Mixture No.	Degree of pulverization in per cent through specified sieves.					Duration of steam treatment.	Molding pressure per square inch.	Compressive strength.	
	No. 20.	No. 40.	No. 80.	No. 100.	No. 200.			Total.	Per square inch.
						Hours.	*Pounds.*	*Pounds.*	*Pounds.*
5	100.0	84.0	55.4	46.5	18.6	5.5	2,300	5,980	1,495
5	100.0	84.0	55.4	46.5	18.6	5.5	4,600	10,800	2,700
6	89.4	57.7	23.7	16.5	11.7	8.0	7,640	12,720	3,180
6	89.4	57.7	23.7	16.5	11.7	8.0	10,000	13,640	3,410
*7	91.6	65.8	33.7	24.7	13.2	8.0	7,640	17,000	4,250
7	91.6	65.8	33.7	24.7	13.2	8.0	10,000	21,280	5,320
8	99.6	72.9	40.4	37.4	20.0	8.0	7,640	19,040	4,760
8	99.6	72.9	40.4	37.4	20.0	8.0	10,000	23,740	5,935

Mixture No.	Molding pressure in pounds per square inch.	Density.		Absorption after 24 hours in water.	
		Air dry.	Dried at 110°.	Air dry.	Dried at 110°.
7	7,640	2.24	2.15	6.1	10.5
7	10,000	2.28	2.19	4.3	9.7
[c]8	7,640	2.23	2.13	5.2	10.1
8	10,000	2.30	2.17	3.6	9.4

[a] Dipped up in baskets. [b] Gravel screenings from dredges. [c] Ground finer than No. 6.

Strong and dense sand-lime bricks are much more readily obtained with Pasig than with beach sand, and this is especially

true when the molding pressure is low. The color of the product is darker and less pleasing, but the bricks made took a fairly good polish, due largely to the presence in quantity of large grains of andesite and basalt rock, as is shown by the granularimetric analysis of mixture 6. Fig. 1, Plate V, is a photograph of a 3 by 3 by 2.25-inch brick made from mixture 6. The front surface had been polished. Fig. 6, Plate VII, is a photograph of a brick made from mixture 7 and shows the perfect soundness after the brick had been subjected to the fire test.

The Pasig sand used in the above experiments contained very little iron, and, thus far, the surface of the bricks has not shown signs of rust stains. Sand from some parts of the Mariquina River contains large quantities of iron, and the use of such material should be avoided.

The granularimetric analyses of mixtures 6, 7, and 8 show a graduated increase in the degree of pulverization and a corresponding increase in strength. A comparison of the granularimetric analysis of the sand as used in mixture 8 with that of the sand as it is received shows that considerable grinding is necessary in order to obtain great strength. However, we have a large quantity of very fine beach sand near at hand, and grinding expenses can be reduced to a low figure by mixing this with coarser available siliceous materials. The lower initial cost of beach sand would also make the production more economical. The results given in Table IX for an equal mixture of Pasig and beach sand were obtained without grinding any of the siliceous materials. A still better product would have been obtained had the beach sand been ground a little before mixing.

TABLE IX.—*Sand-lime bricks made with equal parts of Pasig and beach sand.*[a]

Mixture No.	Granularimetric composition of mixed sands in per cent passing through the specified sieves.					Duration of steam treatment.	Molding pressure per square inch.	Compressive strength.	
	No. 20.	No. 40.	No. 80.	No. 100.	No. 200.			Total.	Per square inch.
						Hours.	*Pounds.*	*Pounds.*	*Pounds.*
9	99.8	75.7	54.8	27.2	3.2	8.0	7,640	10,720	2,680
9	99.8	75.7	54.8	27.2	3.2	8.0	10,000	13,760	3,440

[a] Plate VII, fig. 2, shows the perfect soundness of one of these bricks after it had been subjected to the fire test.

TABLE IX.—*Sand-lime bricks made with equal parts of Pasig and beach sand*—Continued.

Mixture No.	Molding pressure in pounds per square inch.	Density.		Absorption after 24 hours in water.	
		Air dry.	Dried at 110°.	Air dry.	Dried at 110°.
9	7,640	2.14	2.08	7.7	10.5
9	10,000	2.16	2.10	6.5	9.2

Quingua sand.—North of Manila, the Quingua River contains an important amount of pebble sand which is similar to Pasig sand, except that the grains are harder and the quartz a little more abundant. The distance from Manila is considerable (about 35 kilometers), and although transportation by water is possible the river is often too shallow for navigation by launches. Transportation by rail is possible, but the present rates are prohibitive. This sand has not been tested, but its similarity to Pasig sand and greater content of quartz make it certain that it is equally as good, if not better.

Tarlac sand.—Sand from the Tarlac River, at Tarlac, a station situated on the Manila and Dagupan railroad, appears to be the best sand-lime brick sand in Luzon. Owing to the large percentage of quartz and clear glassy plagioclase feldspar, Tarlac sand-lime bricks have a pleasing grayish-white color, and take a good polish with a sparkling, granitic appearance. So far as we have been able to ascertain, there need be no efflorescence even when the percentage of feldspar is as high as in this material. The best results in our simple tests of the fire-resistant properties of Philippine sand-lime bricks were obtained when Tarlac sand was used. Figs. 1 and 4, Plate VII, are photographs of sand-lime bricks made from mixtures 11 and 12, respectively, which remained sound after the fire test. Transportation from Tarlac to Manila must be largely by railroad, and the present high rates are prohibitive.

TABLE X.—*Tarlac sand and its efficiency as a sand-lime brick material.*

Description and classification.	Content of silica.			
	Soluble in hydrochloric acid (HCl).	Soluble in sodium carbonate (Na_2CO_3)	Quartz.	Total silica.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
A clean, sharp, mottled-gray sand which contains magnetite, basalt, olivine, and about 50 per cent of clear, glassy grains readily mistaken for quartz, but which are in reality mostly plagioclase feldspars	0.06	11.82	2.91	66.07

TABLE X.—*Tarlac sand and its efficiency as a sand-lime brick material*—Continued.

GRANULARIMETRIC COMPOSITION.

Sieve No.	10	20	30	40	50	60	80	100	200
Percentage of sand passing through specified sieves	98.5	74.0	41.0	22.0	11.5	6.5	3.5	1.5	0.5

THE SAND-LIME BRICK.

Mixture No.	Degree of pulverization in per cent through standard specified sieves.					Duration of steam treatment.	Molding pressure per square inch.	Compressive strength.	
	No. 20.	No. 40.	No. 80.	No. 100.	No. 200.			Total.	Per square inch.
						Hours.	*Pounds.*	*Pounds.*	*Pounds.*
10	100.0	85.0	71.0	59.0	20.0	5.5	2,300	7,000	1,750
10	100.0	85.0	71.0	59.0	20.0	5.5	4,600	10,060	2,515
11	89.3	24.6	18.3	17.7	10.7	8.0	7,640	13,040	3,260
11	89.3	24.6	18.3	17.7	10.7	8.0	10,000	13,640	3,410
12	99.9	60.5	33.8	26.5	20.5	8.0	7,640	13,880	3.470
12	99.9	60.5	33.8	26.5	20.5	8.0	10,000	15,920	3,980
[a]13	99.9	68.4	40.3	34.9	29.6	8.0	7,640	21,180	5,295
13	99.9	68.4	40.3	34.9	29.6	8.0	10,000	25,960	6,490

Mixture No.	Molding pressure in pounds per square inch.	Density.		Absorption after 24 hours in water.	
		Air dry.	Dried at 110°.	Air dry.	Dried at 110°.
12	7,640	2.19	2.11	3.8	7.5
12	10,000	2.24	2.17	2.4	5.7
13	7,640	2.22	2.16	2.1	5.0
13	10,000	2.29	2.23	1.7	4.1

[a] Ground finer than No. 12.

As with Pasig sand, the natural coarseness of Tarlac sand makes considerable grinding advisable; however, beach sand can be advantageously mixed with the more expensive sand. This, as well as the manner in which the strength of a given mixture may be affected by the quantity of water used, is shown in Table XI.

TABLE XI.—*Sand-lime brick made with a mixture of equal parts of Tarlac and beach sand.*

Mixture No.	Degree of fineness in per cent through the specified sieves.					Percentage of water added to the raw materials.	Molding pressure per square inch.	Compressive strength.		Remarks.
	No. 20.	No. 40.	No. 80.	No. 100.	No. 200.			Total.	Per square inch.	
							Pounds.	*Pounds.*	*Pounds*	
[a] 14	95.7	62.1	49.4	33.7	8.4	8.0	7,640	7,920	1,980	No water was pressed out during the molding.
14	95.7	62.1	49.4	33.7	8.4	8.0	10,000	13,360	3,340	
[b] 15	95.7	62.1	49.4	33.7	8.4	15.0	7,640	14,040	3,510	About 10 per cent of the water was pressed out during the molding.
15	95.7	62.1	49.4	33.7	8.4	15.0	10,000	16,620	4,155	

Mixture No.	Molding pressure in pounds per square inch.	Density.		Absorption after 24 hours in water.	
		Air dry.	Dried at 110°.	Air dry.	Dried at 110°.
15	7,640	2.11	2.09	6.5	7.7
15	10,000	2.19	2.14	4.9	7.5

[a] A comparatively dry mixture. [b] A comparatively wet mixture.

Fig. 5, Plate VII, is a photograph of a brick made from mixture 15, after it had been subjected to the fire test. It remained perfectly sound.

Orani sand.—At the mouth of the Orani River, about 55 kilometers northwest of Manila and directly across Manila Bay, there is an abundance of good sand which can be secured without dredging. The river can be entered by launches, and at low tide the sand can be loaded directly into barges and, without rehandling, towed to Manila. Orani sand is very similar to that from Tarlac except that it is less clean and its color is less attractive. Otherwise, it is as good as Tarlac sand for the manufacture of sand-lime bricks. We obtained a strength of 3,238 pounds per square inch with Orani sand when the molding pressure employed was only 4,600 pounds per square inch.

Volcanic tuff, unusually abundant in Bulacan and along the Pasig River, especially near Guadalupe, is another available source of siliceous material in the vicinity of Manila. It is a fragmental material which contains pieces of scoria, basaltic pebbles, and volcanic ash in varying and nonuniform proportions, and it is easily crushed. When mined, it is so soft that it can be quarried with an ax, but it hardens rapidly on exposure to the air. There are two grades of this water-laid

tuff: (1) coarse, containing numerous fragments of pumice and andesite; and (2) very fine, containing grains of pumice, feldspar, hornblende, and, at times, a little quartz. Our tests include Meycauayan, the best, and Guadalupe, the ordinary volcanic tuff.

TABLE XII.—*Volcanic tuff and its efficiency as a sand-lime brick material.*

Source.	Content of silica.			
	Soluble in hydrochloric acid (HCl).	Soluble in sodium carbonate (Na_2CO_3)	Quartz.	Total silica.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Guadalupe	0.93	20.45	0.00	59.72
Meycauayan	0.02	21.04	2.08	56.99

Mixture No.	Volcanic tuff used.	Degree of pulverization in per cent passing through the specified sieves.					Duration of steam pressure.	Molding pressure per square inch.	Compressive strength.	
		No. 20.	No. 40.	No. 80.	No. 100.	No. 200.			Total.	Per square inch.
							Hours.	*Pounds.*	*Pounds.*	*Pounds.*
16	Guadalupe	100.0	85.0	70.0	50.0	28.5	5.5	2,300	9,000	2,250
16	do	100.0	85.0	70.0	50.0	28.5	5.5	4,600	10,300	2,575
17	do	91.3	71.1	44.4	38.0	25.5	8.0	7,640	10,480	2,620
17	do	91.3	71.1	44.4	38.0	25.5	8.0	10,000	13,640	3,410
18	Meycauayan	68.5	44.9	28.4	23.5	13.0	8.0	7,640	12,440	3,110
18	do	68.5	44.9	28.4	23.5	13.0	8.0	10,000	12,960	3,240
19	do	70.5	48.3	31.2	26.0	17.8	8.0	7,640	18,140	4,535
19	do	70.5	48.3	31.2	26.0	17.8	8.0	10,000	20,140	5,035
20	do	83.3	61.2	38.2	32.5	20.2	8.0	7,640	20,720	5,180
20	do	83.3	61.2	38.2	32.5	20.2	8.0	10,000	22,080	5,520
21	Guadalupe	100.0	82.6	62.8	55.0	41.0	8.0	7,640	14,920	3,730
21	do	100.0	82.6	62.8	55.0	41.0	8.0	10,000	18,280	4,570

Mixture No.	Molding pressure in pounds per square inch.	Density.		Absorption after 24 hours in water.	
		Air dry.	Dried at 110°.	Air dry.	Dried at 110°.
20	7,640	1.87	1.75	6.0	13.4
20	10,000	1.89	1.77	5.9	13.0

Fig. 1, Plate VI, is a photograph of a 3 by 3 by 2.25-inch brick of mixture 18, which was taken after an attempt had been made to polish the front surface. A good polish could not be obtained, and, otherwise, the natural color was a rather unpleasing, dull, light-brown.

Fig 3, Plate VII, is a photograph of a sand-lime brick made

from mixture 19. The cracks were caused by shrinkage due to the tendency of volcanic tuff to flux and melt at the maximum temperature used. In spite of its cracked condition, this brick withstood a pressure of 3,400 pounds per square inch (240 kilograms per square centimeter).

A high content of soluble silica, such as is characteristic of these volcanic tuffs, favors the development of great strength. On the other hand, most of the individual grains are soft, and soft grains are detrimental to the strength. For best results the volcanic tuff should be mixed with hard-grained sands or crushed rock, and for this purpose it is especially adapted both on account of the high content of soluble silica and the ease with which it can be obtained, pulverized, and molded for a maximum strength.

TABLE XIII.—*Sand-lime brick made with a mixture of 1 part of pulverized Guadalupe stone and 3 of natural Pasig sand.*

Mixture No.	Degree of fineness in per cent through the specified sieves.					Duration of steam treatment.	Molding pressure per square inch.	Compressive strength.	
	No. 20.	No. 40.	No. 80.	No. 100.	No. 200.			Total.	Per square inch.
						Hours.	*Pounds.*	*Pounds.*	*Pounds.*
22	99.0	79.0	32.5	26.0	16.5	8.0	7,640	13,200	3,300
22	99.0	79.0	32.5	26.0	16.5	8.0	10,000	13,600	3,400

The advisability of using volcanic tuff or beach sand in conjunction with other available siliceous materials rather than alone is further substantiated by the fact that the sand-lime bricks made from either alone possess the least density and absorb the most water.

Quarry débris is also available. The amount of rock and crushed stone used in Manila for breakwaters, macadam roads, and concrete is considerable, and at present 4 quarry sites are operated to meet the demand; namely, (1) the Rizal, (2) the Manila city quarries at Talim Island, (3) Carabao Island quarry in the south channel entrance of Manila Bay, and (4) the Sisiman quarry near Mariveles.

Crusher-run Sisiman stone contains a large amount of rock flour and sand which is not suitable for road surfacing on account of its poor cementive value. At present this quarry débris is a waste product. Sisiman rock is a gray andesite, while the stone in the other quarries is basalt. Neither contains free silica, but both are high in soluble silica. Owing to this high content

of soluble silica and the hardness of the individual grains, sand-lime brick of the best quality can be manufactured from them. Both materials are especially suited for the manufacture of tiles and ornamental stonework. This is more or less apparent from fig. 2, Plate VI, and fig. 1, Plate IV, which are photographs of 3 by 3 by 2.25-inch sand-lime bricks made from Sisiman and basaltic rock, respectively, although these photographs fail to show the glossiness of the polished front surfaces. The bricks photographed were made from mixtures 22, Table XV, and 23, Table XVI, and it should be borne in mind that, in order to obtain a glossy surface and granitic appearance, the stones were not ground to the degree of fineness necessary to give a high strength. Nevertheless, it is safe to assume that beautiful, polished, dense "artificial marbles" can be made with these materials without reducing the strength below 4,000 pounds per square inch.

TABLE XIV.—*Available quarry débris.*

Rock.	Classification.	Content of silica.			
		Soluble in hydrochloric acid (HCl).	Soluble in sodium carbonate (Na_2CO_3).	Quartz.	Total silica.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Sisiman rock from Mariveles.	A gray andesite which contains no free silica or quartz.	0.37	23.59	0.00	54.77
Basalt rock from Talim Island.	A dark, dense, basaltic rock which shows practically no crystalline structure to the unaided eye and contains no quartz.	1.00	21.17	0.00	54.73

TABLE XV.—*Sand-lime brick made from Sisiman rock quarry débris.*

Mixture No.	Degree of pulverization in per cent passing through the standard specified sieves.					Duration of steam treatment.	Molding pressure per square inch.	Compressive strength.	
	No. 20.	No. 40.	No. 80.	No. 100.	No. 200.			Total.	Per square inch.
						Hours.	*Pounds.*	*Pounds.*	*Pounds.*
22	73.4	48.2	29.4	25.3	16.5	8.0	7,640	10,960	2,740
22	73.4	48.2	29.4	25.3	16.5	8.0	10,000	16,120	4,030

Mixture No.	Molding pressure in pounds per square inch.	Density.		Absorption after 24 hours in water.	
		Air dry.	Dried at 110°.	Air dry.	Dried at 110°.
23	10,000	2.22	2.15	4.4	7.5

TABLE XVI.—*Sand-lime brick made from basalt rock quarry débris.*

Mixture No.	Degree of pulverization in per cent passing through the standard specified sieves.					Duration of steam treatment.	Molding pressure per square inch.	Compressive strength.	
	No. 20.	No. 40.	No. 80.	No. 100.	No. 200.			Total.	Per square inch.
						Hours.	*Pounds.*	*Pounds.*	*Pounds.*
23	75.6	43.7	25.8	22.9	17.0	8.0	7,640	12,080	3,020
23	75.6	43.7	25.8	22.9	17.0	8.0	10,000	15,280	3,820

Mixture No.	Molding pressure in pounds per square inch.	Density.		Absorption after 24 hours in water.	
		Air dry.	Dried at 110°.	Air dry.	Dried at 110°.
23	10,000	2.34	2.28	3.8	6.1

Transportation from the Talim Island quarry, which is near Binangonan, involves only water transportation and costs under fairly economic administration about 1.15 pesos per cubic meter. At the present time the price of crushed stone from Talim is 2.70 to 2.90 pesos per cubic meter at the Manila water front. Sisiman is directly across the bay, and, although about 55 kilometers from Manila, the cost of transportation should not be prohibitive as it would be entirely over deep water. At present, crushed stone from Sisiman costs 3.50 pesos at the Manila water front, but as the quarry débris is a waste product it should cost much less. These costs are so much higher than Pasig sand, which can be purchased for 97 centavos, or less, and the cheaper beach sand, that the manufacturer probably would care to use the crushed rock only for special purposes such as tiles and marble, for which it is especially adapted. However, the cost of production can be retained at a normal figure by mixing the quarry débris with beach sand or crushed volcanic tuff. The latter can be quarried at Guadalupe and transported to the Pasig River for about 43 centavos per cubic meter.

PLANT SITE IN MANILA.

We believe that an economic scheme for utilizing the materials in the vicinity of Manila would be to locate a sand-lime brick plant on the bank of the Pasig River adjacent to the volcanic tuff, and bring limestone from Binangonan. This plan would avoid a long haul to the factory of supplies such as fuel, machinery,

and operating necessities, and put the finished product in close communication with the railroads, and, by short water route, with the ships in the harbor, while close at hand would be the volcanic tuff, and the sands from Pasig, Mariquina, Pasay, and Manila Bay.

The advantages of Manila as a location are all those which accrue from proximity to the main port and largest city of the Philippines. The disadvantages are: (1) the transportation of the limestone over a distance of 7 kilometers by land and 17 by water; (2) the lack of natural protection at Binangonan where an anchorage must be provided for floating stock against severe storms which occasionally sweep Laguna de Bay; and in all probability, (3) the impossibility of using the best sand (Tarlac sand) on account of prohibitive freight rates.

OTHER PLANT SITES.

Although at present Manila appears to be the most suitable place for a sand-lime brick plant, other localities should be given thorough consideration. It is possible that the Visayan Islands and Mindanao will develop more rapidly than the rest of the Philippines, and the growing importance of Cebu, Iloilo, Zamboanga, and Jolo as ports may eventually make a central location more desirable than Manila.

Cebu.—As yet we have made very few sand-lime bricks from raw material other than those already reported. However, some of the important considerations involved have been thoroughly covered by Wallace E. Pratt, of this Bureau, in a recent report[16] on the available raw materials and locations for the Portland cement industry. This and other available information indicate that the vicinity of Cebu, Cebu, the second city in size and importance in the Archipelago, would be a suitable central location for the industry. Large deposits of subbituminous coal occur on the Island of Cebu near the seaport towns of Danao and Naga. Danao is situated 38 kilometers north and Naga 19 kilometers south of Cebu City with which they have railway as well as water connection. Mr. Dalburg of this Bureau has recently estimated that the coal from the Uling field can be delivered at Naga at a cost of 5 pesos per ton, and that at least 800,000 tons are available. The analyses given in Table

[16] *Min. Resources P. I. for 1911, Bur. Sci., Div. Min.* (1912), 111.

XVII show that both the Uling and Danao coal should rank among good limekiln coals, as they are high in hydrogen and volatile constituents, low in ash, sulphur, and fixed carbon, and sufficiently high in calorific value.

TABLE XVII.—*Calorific value and proximate analyses of Cebu coals.*

Constituent.	Danao coal from Camansi mine, average of many samples.	Naga coal from Uling mine.		
		Lower ledge No. 1.	Lower ledge No. 2.	Upper coal.
Moisture	10.01	14.90	11.85	19.23
Volatile combustible matter	[a] 37.93	38.63	38.67	35.44
Fixed carbon	46.30	41.91	45.37	39.10
Ash	5.76	4.56	4.08	6.53
Sulphur	0.77	0.35	0.39	0.43
Calorific value in calories:				
With moisture	6,071	5,744	6,017	5,300
Dry	6,746	6,840	6,897	6,676

[a] Hydrogen=5.90 per cent.

It further appears that sandstone, sand, and limestone of good quality are available in quantity. All the necessary raw materials, including coal, can be found in large quantities about 11 kilometers up the Danao River. The upper coal seams are covered with a sandstone formation varying in thickness up to about 6 meters, and large deposits of soft coralline and hard, pure, calcite limestone are in the immediate neighborhood. The ultimate chemical composition of available sand- and limestone is given in Table XVIII.

TABLE XVIII.—*Analyses of raw materials near Danao.*

Constituent.	Sandstone.	Limestone.	Coralline limestone.
Silica (SiO_2)	72.76	0.38	2.61
Aluminium and ferric oxides (R_2O_3)	15.58	0.18	2.23
Calcium oxide (CaO)	1.42	55.62	52.85
Magnesia (MgO)	0.62	0.00	0.88

Baguio, Benguet.—The lack of local building materials and the great expense of importing the same into the mountain capital of the Philippine Islands has led many to advocate the establishment of a sand-lime brick plant at Baguio. Limestone and soft,

easily crushed sandstone are available in abundance, and some of this material has produced the very best quality of sand-lime brick.

TABLE XIX.—*Sand-lime brick made from Benguet sandstone.*

Mixture No.	Siliceous material.	Dimensions of brick.	Area of bearing surface.	Compressive strength.	
				Total.	Per square inch.
		Inches.	*Sq. in.*	*Pounds.*	*Pounds.*
25	Benguet sandstone No. 1	3×3×2.25	6.75	32,215	4,772
26	Benguet sandstone No. 2	3×3×2.25	6.75	49,410	[a]7,320

[a] Plate V, fig. 2, is a photograph of a brick obtained from this mixture. The front surface has been polished and the color is a very pleasing cream-gray, spotted with quartz. The density of this brick was 1.82 (air-dried), and it absorbed 4.35 per cent of water when submerged for 24 hours.

Aside from the fitness of available raw materials, the possibility of successful, commercial manufacture of sand-lime bricks in this locality involves complicated and uncertain financial considerations.

FINANCIAL CONSIDERATIONS.

In Germany the average cost of manufacturing common sand-lime brick is approximately 6 pesos (3 dollars United States currency) per thousand,[17] and in America the average cost is about 8 pesos for common, and 9 pesos for face, brick. An idea of the cost of manufacture under favorable and unfavorable conditions may be obtained from estimates which were presented to the First Annual Convention, National Association Manufacturers of Sand Lime Products.[18] One estimate which considers coal at 8.50 pesos per ton, lime at 1.60 pesos per barrel (185 pounds, net), and sand at 1.20 pesos per cubic yard, put the cost of manufacture at 10 pesos per thousand. Another placed the total cost at 7.20 pesos per thousand, allowing for slack coal at 2.90 pesos per ton and lime at 80 centavos per barrel. E. C. Eckel[19] has estimated the cost of manufacture at a small plant (10,000 bricks per twenty-four hours), where sand was obtain-

[17] Consul-General Skinner, *U. S. Daily Consular and Trade Reports*, Bureau of Manufactures (1911), No. 9.

[18] *Clay Workers* (1904), 42, 582–591.

[19] Cements, Limes and Plasters. New York (1905), 141.

able at nearby beds, but where lime and coal were expensive. His estimate is as follows:

Item.	Dollars.
Lime, 1.5 tons, at 8 dollars,	12.00
Coal, 1.5 tons, at 4.25 dollars,	6.38
Labor, 6 men,	8.75
Superintendent and office expenses	10.00
Repairs, supplies, etc.	2.00
Interest, depreciation, etc.	6.00
Cost per 10,000 bricks	45.13
Cost per thousand	4.51

A more detailed estimate of the cost of manufacturing 40,000 bricks per day is given by Peppel [20] as follows:

Equipment.

Item.	Dollars.
Land and buildings	15,000
1 wet-pan	1,000
1 ball-mill	500
2 presses	4,400
2 pug-mills	800
Conveyors	6,000
Shafting and belting	3,000
1 100-horsepower Corliss engine	2,500
2 100-horsepower boilers	2,000
1 25-horsepower boiler	300
4 hardening-cylinders, 7 by 60 feet,	8,000
Erecting and insulating cylinders	1,000
Pipes for preliminary heating	1,000
Railroad tracks, etc.	4,500
Total	50,000

Cost of manufacture, 40,000 bricks.

Item.	Dollars.
Sand, 157 cubic yards, at .07 dollar,	11.00
Lime, 11 tons, at 4 dollars,	44.00
Coal, 3 tons, at 2.25 dollars,	6.75
Repairs	5.00
Oil and grease	3.00
Labor, 40 men, at 1.35 dollars,	54.00

[20] *Trans. Am. Ceramic Soc.* (1902), 4.

Cost of manufacture, 40,000 bricks—Continued.

Item.	Dollars.
Fireman, at 2.50 dollars,	2.50
Office expenses	20.00
Depreciation and interest, 12 per cent,	20.00
Total	166.25
Selling expenses, 10 per cent,	16.00
Cost of manufacturing 40,000 bricks	182.25
Cost of bricks per thousand	4.55

These figures show the manner in which the cost of manufacture is influenced by local conditions such as the cost of fuel, labor, supplies, machinery, building, raw materials, quality of bricks produced, etc. They also show that the cost of production can be maintained at a comparatively low figure in spite of rather unfavorable conditions.

In the Philippines, fuel for burning the limestone and for generating power is certain to be expensive even if local coal is used unless it is found practicable to locate the limekilns near a mine or an available source of firewood. Other items for which higher costs must be allowed, as compared with practises in the United States and Germany, are first cost of plant, administrative supervision, plant depreciation, repairs, supplies, and transportation by land. More definite information in this respect will be combined with an estimate of the cost of manufacturing sand-lime brick at the suggested site on the Pasig River. This estimate is based on a plant having a capacity of 20,000 bricks in twenty-four hours, and 10,000 pesos additional is allowed for extra machinery and molds for building blocks, tiles, ornamental products, etc. The cost of machinery and supplies is about 25 per cent more than the average price in the United States where ordinarily a well-equipped sand-lime brick plant with a daily capacity of 20,000 bricks costs, independent of site and building, about 40,000 pesos. To this sum of 60,000 pesos, 10,000 pesos are added for a large factory site, and 10,000 pesos for buildings. This brings the total cost of the plant to 80,000 pesos. Three estimates, including our own, of the amount of labor and raw materials required for 20,000 bricks are given in Table XX.

TABLE XX.—*Estimates of the amount of labor and raw materials for a daily production of 20,000 bricks.*

Labor and materials.	Common bricks.		9-inch bricks of best quality with an average equipment.
	International Sand-lime Brick and Mfrg. Co., Melbourne, Australia.[a]	Ideal Brick Machinery Co., New York City.[b]	Bureau of Science.
Foreman	1		1 (European or American).
Engineer	1	1	1 (Filipino).
Fireman	1	1	Do.
Common laborers	8	1	14 (Filipinos).[c]
Sand or crushed stone	[d] 52 tons	[d] 42.5 tons	70 tons = 60 cubic yards = 46 cubic meters.
Quicklime or its equivalent in hydrated lime.	3.0 tons	3.0 tons	6.0 tons — 10 per cent slaked lime.
Coal or its equivalent in wood, gas, or oil.	3.0 tons	2½ tons to 4 tons.	3.0 tons.

[a] *Cem. & Eng. News* (1911), 23, 130.

[b] Sand-Lime Bricks and Blocks: Ideal Brick Machinery Co., New York City.

[c] This figure includes men for handling the sand, lime, and bricks.

[d] We consider that the above estimates of 52 and 42.5 tons of sand are much too low as the average weight of good sand-lime bricks is about 8 pounds. Likewise, the lime estimates of 3 tons must be regarded as inadequate for a uniform, good product. Our estimates for sand and lime are higher than is necessary for common brick. They are based on the requirements of face brick.

The economic problems involved in the cost of quarrying, dredging, transportation, and manufacture, and the more vital one of obtaining the best results in the use of the materials is beyond the scope of this paper. For this reason an estimate on the minimum cost of production is impossible, but a careful consideration of local conditions has enabled us to make a fairly accurate estimate. In Manila common laborers receive from 80 centavos to 1 peso per day. For the purpose of this estimate their efficiency is rated at one-half that of American or European workmen. Salaries for foreign technical men are from 15 to 30 per cent higher in Manila than in the United States, but good Oriental engineers and firemen are available at comparatively low wages. It is probable that a local sand-lime brick industry would have to depend on coal imported from Japan or Australia for fuel.[21] The price of this coal in Manila

[21] Recently Borneo crude oil such as is used in gas engines has been purchased on the Manila market for 0.0462 peso per liter. It is sold in drums of 295 liters, and samples tested showed 10,515 total calories and an available heating value of 9,712 calories.

varies from 9.50 pesos to 10.50 pesos per metric ton. Good coal for generating power and burning limestone can be obtained, but a careful selection is necessary as shown by the analyses given in Table XXI.

TABLE XXI.—*Analyses* [a] *of typical coals received in Manila since December 1, 1910.*[b]

Numbers, except as otherwise indicated, represent percentage.

	Japan.			Australia.		Borneo.	
	Miike nut.	Moji Yamano lump.	Karatzu Ochi lump.	Newcastle Seeham "Best screened."	Newcastle Browns Duckenfield Merthyr.	Labuan.	Cowie Harbor, British North Borneo. (Air dried.)
Percentage of fine coal (through ⅛-inch mesh)	97.71	40.50	----------	----------	----------	----------	----------
Percentage of slack (through ¼-inch mesh)	19.64	12.60	----------	----------	----------	----------	----------
Number of tons in cargo	2,740	1,000	3,400	3,830	5,021	1,791	----------
Proximate analysis:							
Moisture	0.43	1.83	2.32	2.56	2.41	6.14	1.01
Volatile combustible matter	41.45	38.85	39.65	35.08	33.69	43.76	42.68
Fixed carbon	47.59	43.39	47.59	51.96	53.65	46.21	39.42
Ash	10.53	15.93	10.44	10.40	10.25	3.89	16.89
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur (separately determined)	2.00	1.61	1.01	0.51	0.96	0.48	----------
Coking quality	coking	coking	coking	coking	coking	noncoking	----------
Available heating value in colories by calorimeter	[c] 7,402	6,403	6,627	6,711	6,640	6,508	----------

[a] Analyses by Forrest B. Beyer.

[b] Cox, A. J., *This Journal, Sec. A* (1912), **7**, 4.

[c] Miike coal has the highest calorific value, but its easily fusible ash and high content of sulphur are detrimental to its efficiency.

The cost of manufacturing sand-lime brick would be excessive if the manufacturer paid the prevailing Manila market prices for lime. One merchant quoted 30 pesos per ton for quicklime which is considerably more than the cost of Portland cement. Another submitted figures on poor material of local manufacture which were equivalent to air-slaked rock lime at 17.08 pesos per ton. This high market value is largely due to the crude process of local manufacture and to the small and

irregular demand.[22] A steady demand of 3 tons per day would probably lower the price to not more than 25 per cent in excess of the average cost in the United States or Europe. An estimate of 16 pesos per ton for good quicklime is reasonably high.

According to the above estimates the maximum cost of manufacturing 20,000 sand-lime bricks daily and selling expenses would be as follows:

Item.	Pesos.
Interest on investment at 8 per cent (300 working days per year)	21.32
Foreman (American or European),	8.00
Engineer (Filipino),	4.00
Fireman (Filipino),	2.00
Laborers (Filipinos), 18, at 90 centavos,	16.20
Sand, 46 m^3 (70 tons), at 97 centavos,	44.62
Lime, 6 tons, at 16 pesos,	96.00
Coal, 3 tons, at 10 pesos,	30.00
Oil and waste	4.00
Wear and tear	10.00
Total	236.14
Selling expenses at 10 per cent	23.62
Cost of manufacturing 20,000 bricks	259.76
Cost of manufacturing 1,000 bricks	13.00

This estimated cost of 13 pesos per thousand 9-inch face bricks is based on liberal operating expenses. Good management and the installation of limekilns ought to reduce the cost below 11 pesos, and a further saving of raw materials would result from the manufacture of hollow bricks and building blocks. However, even a cost of 13 pesos per thousand is reasonably cheap when compared with the local price of other materials of the same class. Concrete construction work is expensive. At the water front, cement costs from 4.50 to 5.50 pesos per barrel; gravel, 1.80 to 2.20; sand, 0.98 to 1.20; and crushed stone, 2.70 to 3.50 pesos per cubic meter. Prepared cement and clay products are even more expensive, as shown by the following prices furnished by the Bureau of Supply under date of August 14, 1912.

[22] The value of lime imported into the Philippine Islands during the years 1907 to 1911 averaged only 920 pesos annually. When imported from foreign countries it is subjected to a customs tariff of 8 centavos per 100 kilograms.

TABLE XXII.—*Manila prices of clay and cement products.*

Article.	Dimensions.	Cost.
	Inches.	
Common brick (soft)	From 8.25×3.9×1.8 to 9×4.4×2	25 pesos per thousand and up.
Fire brick	8.9×4.4×3.1	89 pesos per thousand and up.
Floor tiles (glazed)	12×12	77 pesos per thousand and up.
Vitrified clay water pipe	10×24	2.904 pesos each.
Do	8×24	1.470 pesos each.
Do	4×24	0.660 peso each.
Cement floor tiles	12×12	From 30 to 77 pesos per 1,000.
Cement water pipes	12 (diameter)	0.907 peso per linear foot.
Do	8×36	1.034 pesos per linear foot.

In the United States, "the average price per thousand received for common sand-lime brick was $6.36 in 1910, as compared with $6.39 in 1909, and $6.33 in 1908; for front brick $10.90 as against $11.98 in 1909, $12.16 in 1908, and $10.96 in 1907."[23] In Manila the market value ought to be much greater, but, according to our estimate of the cost of producing front brick, even the above selling prices should leave a good margin of profit.

SUMMARY.

1. In the Philippines conditions are very favorable for the manufacture of brick and artificial stone from sand and lime if the enterprise is carefully and conservatively managed. The selection of a factory site, raw materials, process of manufacture, and machinery should receive unusual care.

2. The best location for the first plant is probably in the vicinity of Manila. Tests and information concerning the available raw materials indicate the advantages of locating a sand-lime brick plant near the Pasig River at Guadalupe.

3. The cost of manufacturing and selling 20,000 9-inch bricks of the best quality is estimated not to exceed 13 pesos (6.50 dollars United States currency) per thousand. Compared with other Philippine building materials of equal value this is very reasonable, and the profit of a plant could be increased by extending its operations to include the manufacture of lime, hollow building blocks, tiles, slabs, marbles, ornamental stones, etc.

[23] *Min. Resources U. S. Geol. Surv.* (1910), 626.

ILLUSTRATIONS.

PLATE I.

A segment of a reinforced beam of reconstructed stone.

PLATE II.

An exhibit of reconstructed stones and marbles at the 1907 Building Trades Exhibition, Olympia, England.

PLATE III.

FIG. 1. A sand-lime brick which disintegrated during the hardening process on account of the presence of unslaked, free lime.
2. Sand-lime brick made from Maytubig beach sand (*cf.* mixture 3, Table VII).

PLATE IV.

FIG. 1. Sand-lime brick made from Talim quarry, basalt rock (*cf.* mixture 23, Table XVI).
2. Sand-lime brick made from Maytubig beach sand (*cf.* mixture 4, Table VII).

PLATE V.

FIG. 1. Sand-lime brick made from Pasig sand (*cf.* mixture 6, Table VIII).
2. Sand-lime brick made from crushed Benguet sandstone (*cf.* mixture 25, Table XIX).

PLATE VI.

FIG. 1. Sand-lime brick made from Meycauayan volcanic tuff (*cf.* mixture 18, Table XII).
2. Sand-lime brick made from Sisiman quarry andesite rock (*cf.* mixture 22, Table XV).

PLATE VII.

Sand-lime bricks made from Philippine raw materials, heated to 1,100° and plunged into water.

FIG. 1. Coarsely ground. Tarlac sand, brick mixture.
2. Brick mixture containing equal parts of Pasig and beach sand.
3. Volcanic tuff, brick mixture.
4. Finely ground. Tarlac sand, brick mixture.
5. Brick mixture containing equal parts of Tarlac and beach sand.
6. Pasig sand, brick mixture.

PLATE VIII.

Common sand-lime brick made from Philippine raw materials. (Upper, *cf.* mixture 10, Table X; lower, *cf.* mixture 16, Table XII.)

FIG. 1. Before subjection to crushing in the compression test.
2. After subjection to crushing in the compression test.

TEXT FIGURE.

FIG. 1. Map of the vicinity of Manila (1 millimeter equals 1 kilometer).

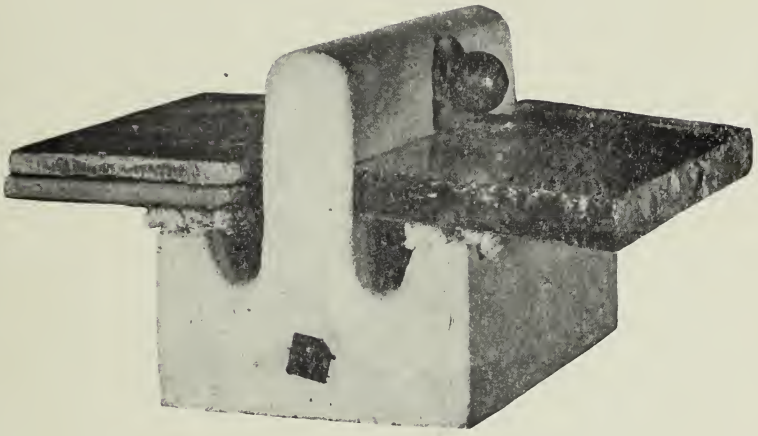

PLATE I. SEGMENT OF A REINFORCED BEAM OF RECONSTRUCTED STONE.

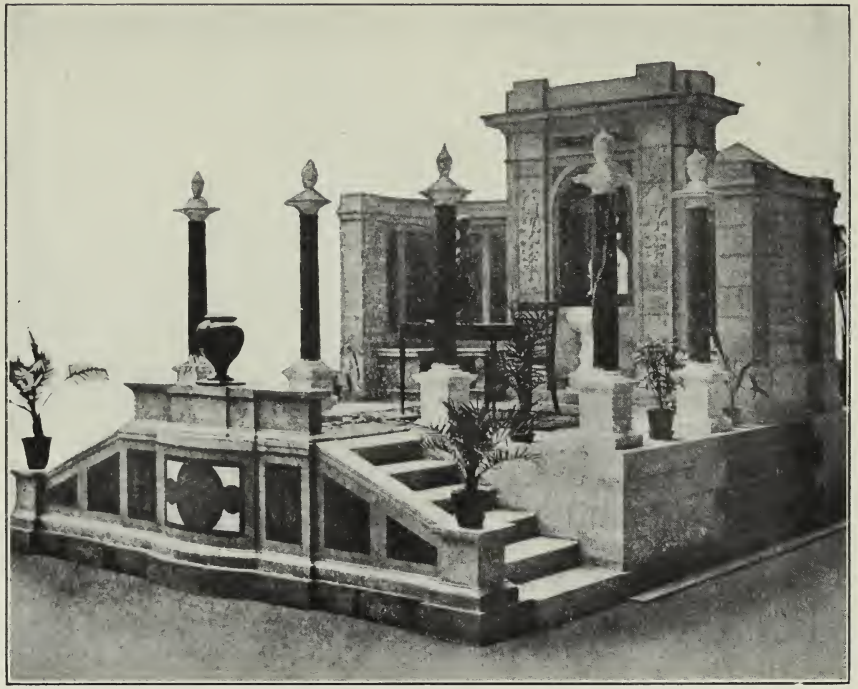

PLATE II. RECONSTRUCTED STONES AND MARBLES.

Fig. 1. Sand-lime brick disintegration caused by the hydration of free lime during the hardening process.

Fig. 2. Maytubig beach sand, brick mixture.

PLATE III.

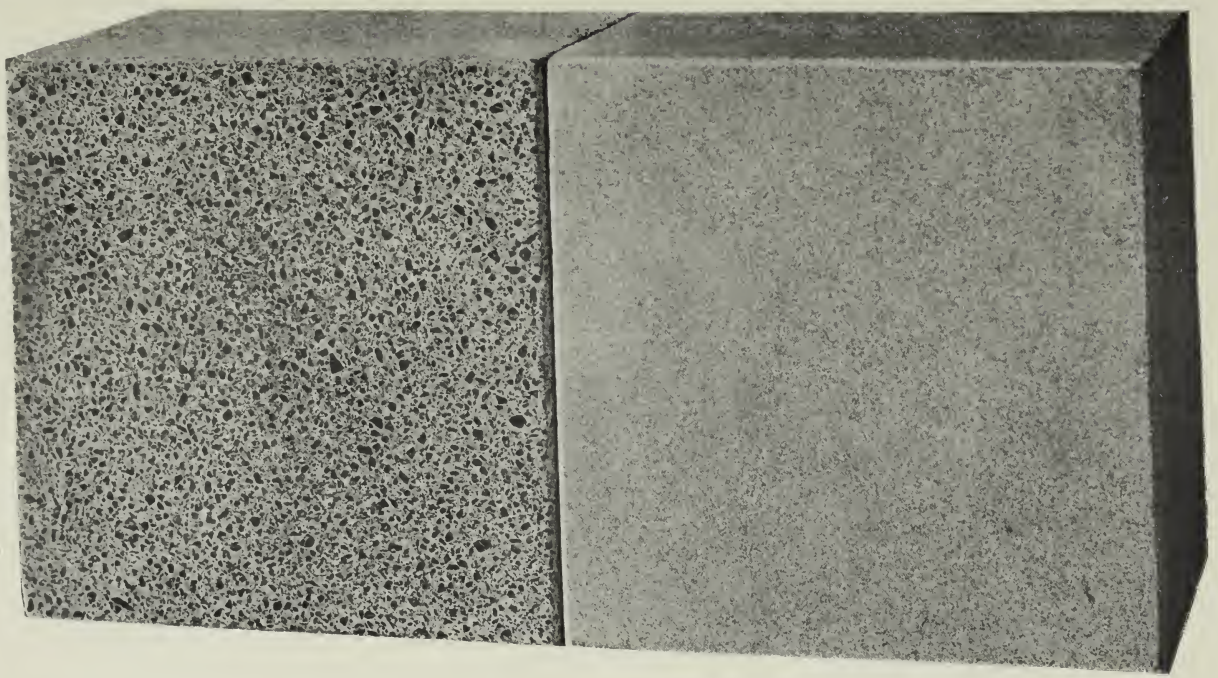

Fig. 1. Talim basalt quarry débris, brick mixture.

Fig. 2. Maytubig beach sand, brick mixture.

PLATE IV.

Fig. 1. Pasig sand, brick mixture.

Fig. 2. Benguet sandstone, brick mixture.

PLATE V.

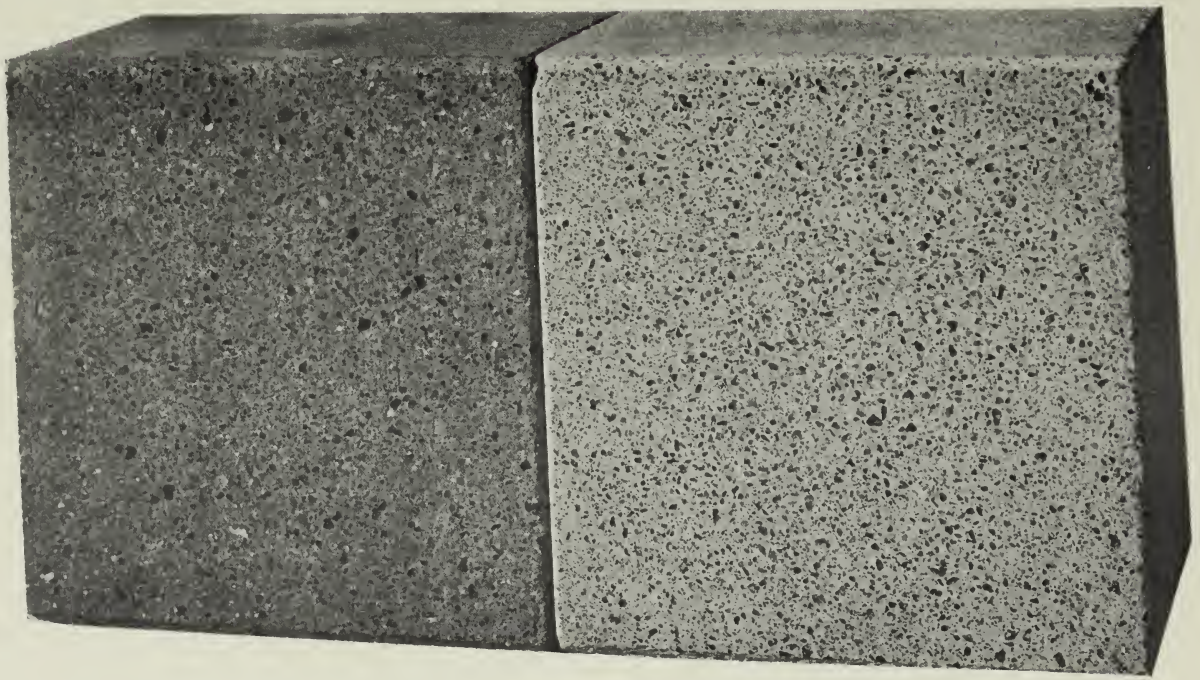

Fig. 1. Meycauayan volcanic tuff, brick mixture.

Fig. 2. Sisiman andesite quarry débris, brick mixture.

PLATE VI.

PLATE VII. SAND-LIME BRICKS MADE FROM PHILIPPINE RAW MATERIALS, HEATED TO 1,100° AND PLUNGED INTO WATER

Fig. 1.

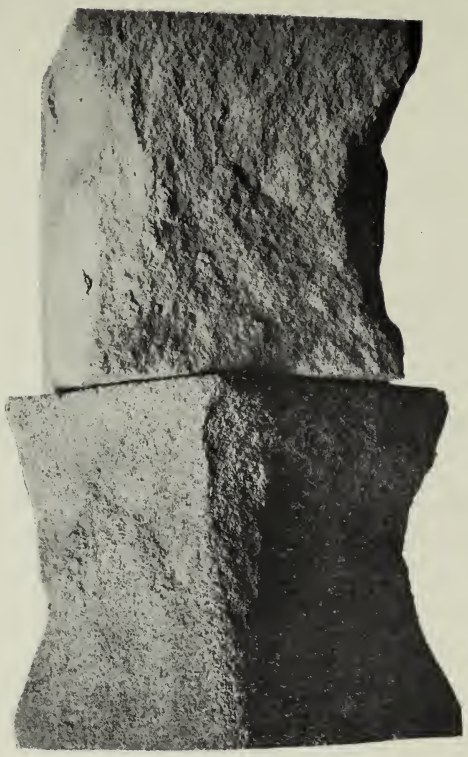

Fig. 2

PLATE VIII. COMMON SAND-LIME BRICK (PHILIPPINE RAW MATERIALS) BEFORE AND AFTER CRUSHING.

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